2.4GHz SAW filters using AlN deposited on off-angle R-plane sapphire substrates by MOVCD

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A-plane AlN films deposited on off-angle R-plane sapphire substrates, in which the surface plane was tilted towards [1-101] direction, were shown to effectively restrain the generation of inverted twins. The total crystal quality of the AlN was found to depend on the direction of the off-angle by the results of X-ray diffraction and TEM images. 2.4 GHz SAW filters were realized using the optimized AlN on the off-angle sapphire substrate.
KEYWORDS: A-plane AlN, off-angle, R-plane sapphire, MOCVD, GHz band, SAW, inverted twin, SEM, X-ray diffraction, TEM

The heterostructure that consists of aluminum nitride on sapphire (AlN/α-Al_2O_3) exhibits high surface acoustic wave (SAW) velocity of approximately 6,000m/sec and shows small temperature coefficient of delay time (TCD). Therefore AlN/α-Al_2O_3 is a promising candidate for the SAW devices operating in a GHz band, which is required for wireless communication systems. In particular, the epitaxial growth of A-plane AlN has been achieved on R-plane α-Al_2O_3 substrates and the highest electromechanical coupling coefficient (k^2) of 0.8% has been reported [1][2]. However, the epitaxial growth of A-plane AlN is known to be difficult since the preferential orientation of AlN epilayer is (0001).

In this study, systematic optimization of the growth conditions of A-plane AlN was carried out during the metalorganic chemical vapor deposition (MOCVD) using R-plane α-Al_2O_3 substrates in order to extract the above-mentioned potential properties. Particular change in the growth conditions was found to generate inverted twins [3] in the epilayer, which caused a reduction of the value of k^2. The use of off-angle R-plane sapphire substrates, in which the surface plane was tilted towards [1-101] direction, was shown to effectively restrain the generation of the inverted twins. Furthermore, 2.4GHz SAW filters was realized using the optimized AlN on the off-angle α-Al_2O_3 substrate.

The AlN films were deposited by MOCVD on 3-in.-diam. R-plane sapphire substrates with off-angle of 0 and $\pm$4 degrees toward the [1-101] direction. The source precursors were TMA and NH_3. The definition of off-angle is shown in Fig.1. Prior to AlN deposition, the substrates were annealed in a H_2 ambient for 30 min and subsequently exposed in a mixed flow of NH_3 and H_2 for 5 min as an initial nitride procedure. Then AlN epitaxial growth was conducted by supplying TMA in the gas flow. The value of Ⅴ/Ⅲ ratio was kept at 2,000 during the growth. The reactor pressure and the temperature were 20 Torr and 1150℃, respectively. 2.4 GHz SAW filters with 0.58 μm L&S were fabricated on these substrates using submiron fabrication techniques. The surface images were observed using a SEM. The X-ray rocking curve was also taken. The structure of the heteroepitaxial interface was observed using a cross-sectional transmission electron microscopy (TEM). The SAW device performance was measured by a network analyzer.

The as-deposited AlN films exhibited tetrahedral facets having {001} and {101} planes, as shown in the SEM image in Fig. 2. The direction of the tetrahedron was found to be inverted by inverting the sign of the off-angle. The direction of it for the films grown on an on-axis R-plane sapphire did not show remarkable preference among wafers and in-wafer. Furthermore, we sometimes observed the inverted twins, which coincided with the coexistence of tetrahedron shape in the opposite direction. It is predicted that the subtle angle deviation from just on–axis orientation causes these phenomena, i.e. such off-axis plays an important role in restraining the inverted twins.

The results of X-ray diffraction and TEM indicated opposite effects of the sign of the off-angle. The value of FWHM of rocking curve decreased with decreasing the value of tilted angle. Thus, AlN films deposited on the -4 degrees off-angle R-plane sapphire exhibited the best crystal quality among three samples. The films grown on the -4 degrees off-angle showed clear lattice images, which were revealed from the TEM images. Conversely, AlN on 0 or +4 degrees off-angle substrates showed moiré fringes in the TEM images of the vicinity of the interfaces between AlN and sapphire. From these results, the fluctuating atomic arrangement originated from the initial stage of the growth is considered to influence the total crystal quality of AlN.

Fig.3 shows the frequency response of a 2.4GHz SAW delay line fabricated using the AlN films grown on the -4 degrees off-angle sapphire. The AlN films on the -4 degrees off-angle sapphire was confirmed to be of good quality sufficient for GHz SAW devices. In addition, the 2.4 GHz front-end spread spectrum (SS) SAW matched filters will be presented.

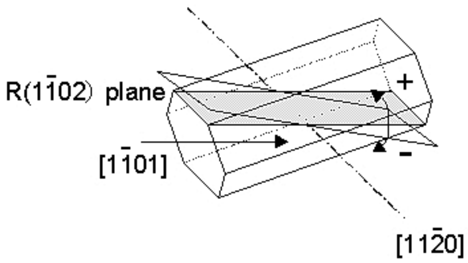

Fig. 1 The definition of off-angle of R-plane sapphire.

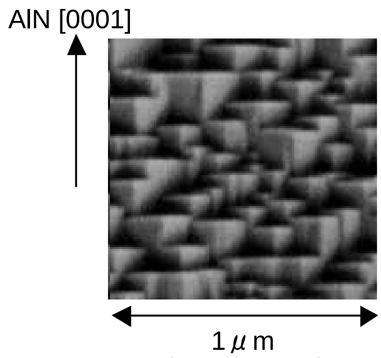

Fig. 2 SEM surface image of as-deposited AlN.

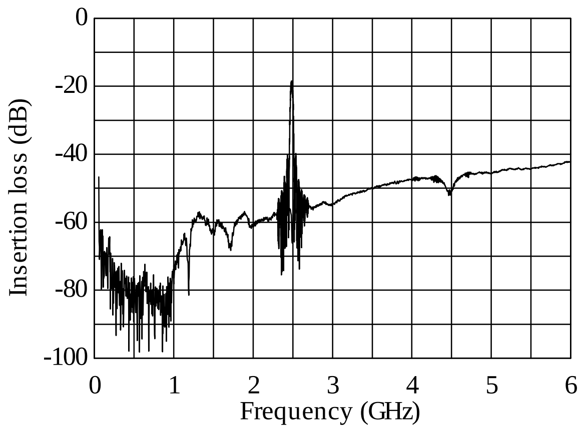

Fig. 3 The frequency response of a 2.4GHz SAW delay line fabricated using the AlN films grown on the -4 degrees off-angle sapphire.

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